LA-UR-21-32141
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Title:	Evaluation report on the Thermo Scientific TruDose (neutron,gamma) EPD3
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Intended for:	Report
Issued:	2021-12-13

Evaluation report on the Thermo Scientific TruDose (neutron,gamma) EPD3 12/08/2021

This report summarizes an evaluation study on the Thermo Scientific TruDose n/γ EPD3 by LANL's RP-SVS group. Two EPD3s were received for assessment (SNs 7500100 and 7500108) along with an EPD3 desktop reader. The evaluation included intercomparisons with Thermo's N2 EPD which is in wide circulation at LANL but is no longer commercially available. A favourable assessment of the TruDose EPD3 would help support it as a viable option to replace the N2 EPD. The data and observations included in this report could also serve as the basis of a Technical Basis Document for the use of the EPD3 at LANL.

The report is divided into two sections. The first is an initial assessment of the EPD3 that included the following measurements and observations:

- Energy response in neutron reference fields at the Central Health Physics Calibration Facility (TA36-0214).
- A linearity response study in a bare ^{252}Cf reference field.
- The angular response of the TruDose EPD3 in a bare ^{252}Cf reference field.

The second part of the evaluation was an intercomparison study with the N2 EPD. These measurements and comparisons included:

- Energy response in neutron and gamma reference fields at the Central Health Physics Calibration Facility. The neutron measurements were at an opportunity to evaluate the repeatability of the earlier EPD3 results.
- Relative response of the TruDose EPD3 and the N2 EPD in neutron fields when mounted on a realistic phantom.
- A comparison of the respective ease of use and the specifications/capabilities/functions of the two EPD models.

General description of the EPDs:

Both EPD models rely on solid state diodes to register charged particle events above an energy threshold. Each EPD use two diodes to detect neutron-induced counts: one registers elastically scattered protons from fast neutron interactions in a thin polyethylene converter while a second diode detects thermal neutrons scattered by the body (i.e. albedo neutrons) via a ^{6}Li-enriched converter. The TruDose EPD has three registers devoted to gamma (secondary electron) detection while the N2 has just two.

Both EPDs can be configured (via IR or desktop readers) using PC software. Unfortunately, the readers are not compatible i.e. mixing and matching is not possible. Though it is our understanding that Thermo is developing a TruDose reader which will be backwards compatible.

The PC software user interface for the two EPDs bear no resemblance appearance-wise but all the features and parameter settings (and more) associated with the N2 EPD are also available with the TruDose software.

Initial EPD3 measurement data:

<u>Neutron energy response</u>

The neutron energy response of the TruDose EPDs was studied using a bare and moderated Cf source (S/N FTC-CF-7167) as well as a NIST-traceable AmBe source (S/N 8969NK). The Cf source was moderated by polyethylene spheres of differing wall thicknesses (1”,2” and 3”) and by a 30cm diameter D_2O sphere to produce different reference fields. These neutron source techniques ranged in average energy from 0.5 to 3.4 MeV. The conventionally true dose (CTV) rates (Hp(10,0)) listed in Table 1 were determined through MCNP calculations normalized to the NIST-traceable emission rate of the source.

Table 1. EPD3 neutron energy response

source	technique	Eavr. (MeV)	CTV (mrem/h)	t(s)	delivered dose (mrem)	S/N	Neutron dose (mrem)	Gamma dose (mrem)	AN_1	FN_2	Norm. response
Cf	Bare	1.78	772.4	932.2	200	100	206.4	8.62	193	334	1.03
Cf	Bare	1.78	772.4	932.2	200	108	190.4	8.58	180	303	0.95
AmBe	bare	3.36	113.2	1590	50	100	58.8	6.63	27	133	1.18
AmBe	bare	3.36	113.2	1590	50	108	57.2	6.15	36	120	1.14
AmBe	bare	3.36	113.2	1590	50	100	53.2	6.36	34	115	1.06
AmBe	bare	3.36	113.2	1590	50	108	52.8	6.03	28	113	1.06
Cf	3"PE	0.97	223.3	1612	100	100	188.4	14.45	327	149	1.88
Cf	3"PE	0.97	223.3	1612	100	108	185.2	14.22	317	151	1.85
Cf	1"PE	1.28	539.5	1334.7	200	100	224.4	12.39	330	256	1.12
Cf	1"PE	1.28	539.5	1334.7	200	108	246.5	12.28	337	289	1.23
Cf	2"PE	1.05	348.1	1551.1	150	100	238.0	14.9	408	192	1.59
Cf	2"PE	1.05	348.1	1551.1	150	108	232.0	14.4	375	211	1.55
Cf	D_2O	0.50	194.0	3712	200	100	496.0	30.2	1008	248	2.48
Cf	D_2O	0.50	194.0	3712	200	108	487.6	29.16	992	231	2.44

The TruDose EPD3s were centrally mounted on a 40x40x15cm Lucite phantom and irradiated simultaneously. The Cf-based exposures were done at 100cm while the AmBe runs were done at 50cm. Note that some measurements, as shown in Table 1, were replicated but not necessarily on the same day.

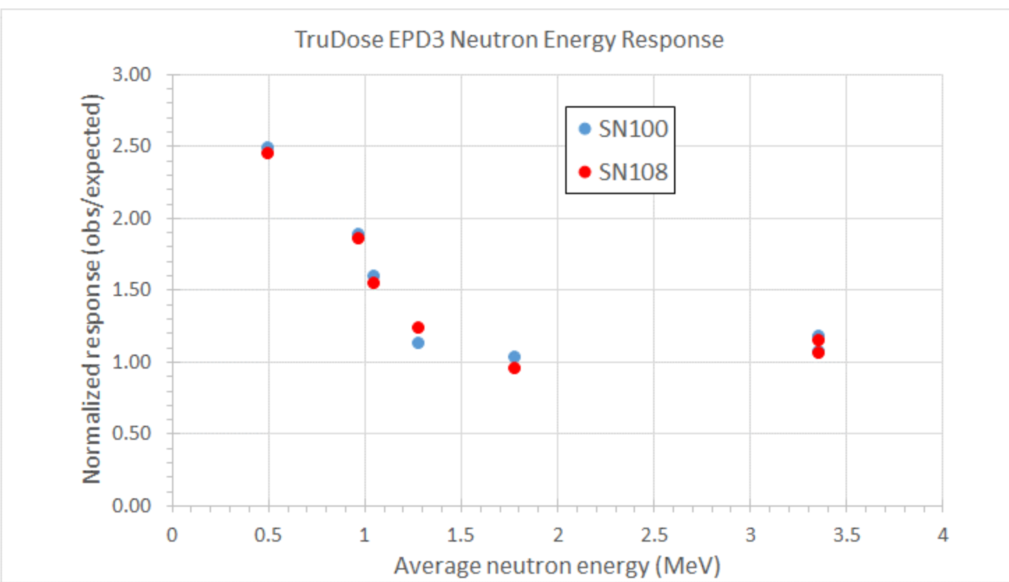
The dose data recorded by the EPD3s in Table 1 and throughout the entire evaluation study are "as found" readings as the EPDs were not calibrated at LANL prior to the study – relying instead on the default factory calibration for both neutron and gamma dose.

Table 1 also lists the fast (FN_2) and albedo counts (AN_1) for each exposure. These counts were the basis for the neutron dose calculation.

The last column in Table 1 gives the normalized response of the EPD3s relative to the CTV dose. Figure 1 illustrates the increasingly higher normalized response of both EPD3s as average energy decreased. The EPD3s performed in a very similar manner in each reference field – as made clear in Fig. 1.

The energy response data suggests a calibration in a bare Cf field will give the most conservative calibration factor (as is also the case for the N2 EPD). Consequently, in moderated fields (average energies <1 MeV), the TruDose EPD3 can be expected to over respond by more than a factor of two.

Figure 1. EPD3 neutron energy response



<u>Linearity study in a bare ^{252}Cf neutron reference field</u>

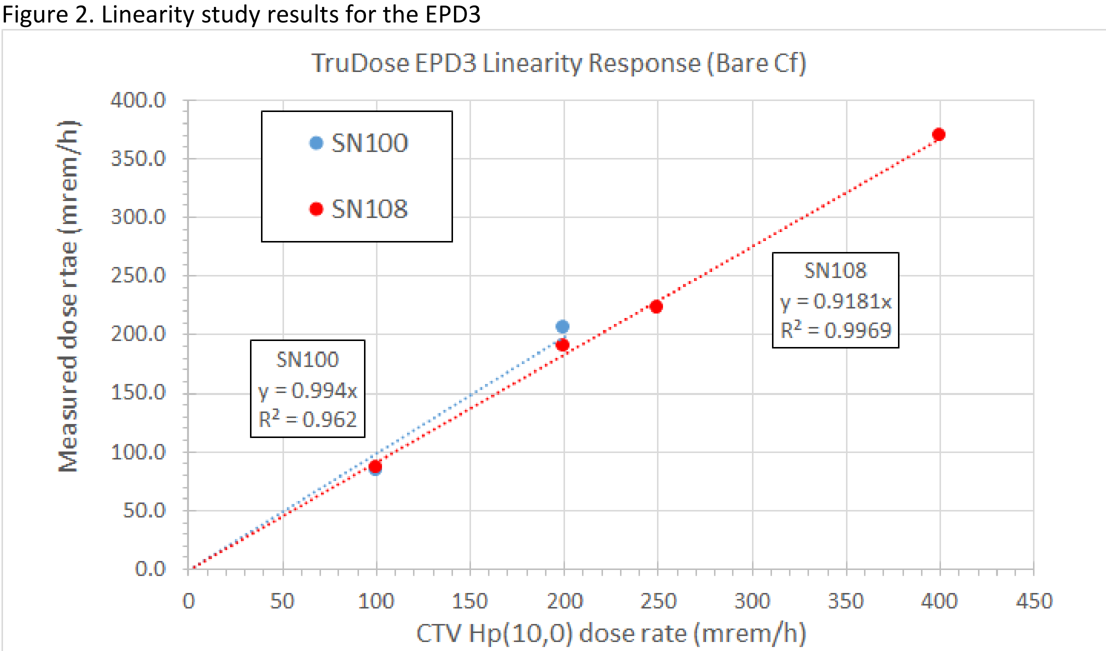
For this study, the TruDose EPD3s were again centrally mounted on a standard 40x40x15cm Lucite phantom and irradiated simultaneously. The phantom was positioned 100cm from the NIST-traceable Cf source (S/N FTC-CF-7167) and a range of CTV doses were delivered by varying the exposure time. After each exposure, the measured neutron (and gamma) dose was recorded for each EPD3 before resetting the respective dose registers prior to the next exposure.

Table 2 summarizes the data recorded during this study while Figure 2 displays the dose data in graphical form. Note that EPD3 7500100 failed during this study (error code "F071 DP") and

Table 2. Linearity study in a bare Cf field

CTV (mrem/h)	t(s)	delivered dose (mrem)	S/N	Neutron dose (mrem)	Gamma dose (mrem)	AN_1	FN_2	normalized response
766	470.3	100	100	84.4	4.36	74	142	0.84
766	470.3	100	108	87.2	4.30	91	128	0.87
772.4	932.2	200	100	206.4	8.62	193	334	1.03
772.4	932.2	200	108	190.4	8.58	180	303	0.95
766	1148	250	108	222.2	10.64	225	335	0.89
766	1879.3	400	108	369.6	17.31	367	566	0.92

Figure 2. Linearity study results for the EPD3



was not revived until after this linearity study. Also note that these measurements were spread over several days (hence the difference in the CTV dose rates). The 200 mrem data was recorded earlier as part of the energy dependence study (Table 1).

A least squares fit to the data indicated good linearity ($r^2 > 0.96$ in both cases) and average normalized responses that were within 10% of unity.

Angular dependence study

An angular dependence study in a bare Cf field was conducted by rotating the Lucite phantom about the vertical axis down the center of the phantom's front face. The CTV neutron dose as a function of angle (θ) was based on fluence-to-dose conversion coefficients from ICRU-57. These conversion coefficients were folded into the MCNP6-calculated fluence incident on the phantom's front face to derive CTV dose rates as a function of angle.

Table 3 summarizes the data collected for the two TruDose EPD3s. It can be seen that the normalized response (relative to the angular-dependent CTV dose) monotonically decreased as the angle increased. This finding is consistent with earlier studies with the N2 EPD at LANL (albeit using a different dosimetric quantity), in the literature (Nunes and Surette, Rad. Prot. Dosim., 113(1),14,2005) and a PTB (Germany) evaluation.

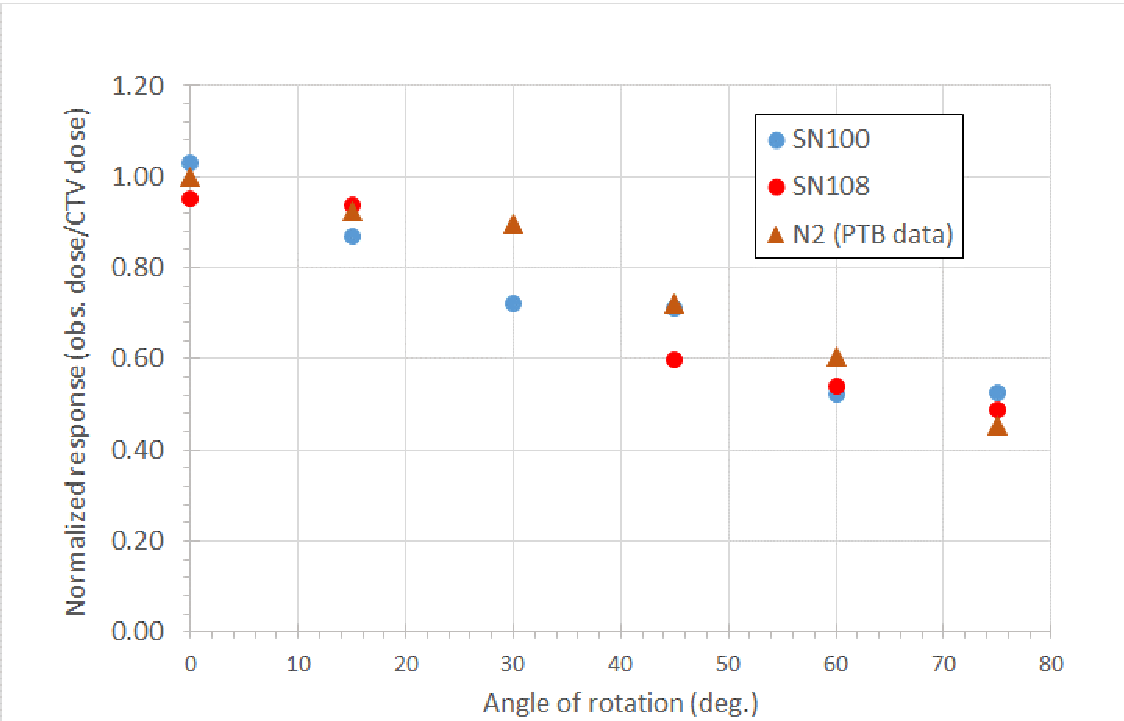
Again, both EPD3s behaved in a similar manner though SN 7500108 did fail during the measurement at 15^{o}. No dose was reported but the fast and albedo counts were recorded and the dose reconstructed based on the respective factory calibration factors. A full recovery was made (by clearing the fault condition via the PC software) prior to the 60^{o} exposure.

Table 3. Angular dependence in bare Cf field

θ (deg.)	S/N	CTV Hp(10,θ)	N(mrem)	G(mrem)	AN_1	FN_2	Normalized response
0	100	200.4	206.4	8.62	193	334	1.03
15	100	243.0	171.6	8.72	162	281	0.71
30	100	247.5	147.2	8.50	152	232	0.59
45	100	226.4	136.0	8.51	142	243	0.60
60	100	200.7	88.4	7.87	109	151	0.44
75	100	133.4	57.2	6.81	67	92	0.43
0	108	200.4	190.4	8.58	180	303	0.95
15	108	243.0	185.5*	0.01	145	295	0.76
45	108	226.4	114.8	8.11	119	194	0.51
60	108	200.7	91.2	7.69	104	144	0.45
75	108	133.4	53.2	6.62	77	78	0.40

* Dose reconstructed from AN_1 and FN_2 counts

Figure 3 displays the angular dependence data in graphical form. This Figure also includes the angular dependence data measured by PTB for the N2 EPD. The performance of the



two EPD models is seen to be quite similar in that both show a decreased response with increasing angle of incidence.

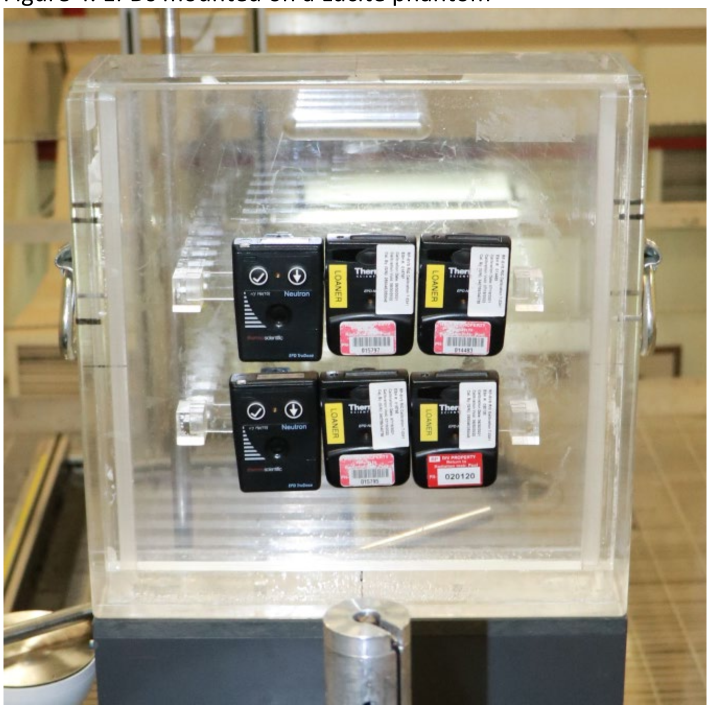
<u>Intercomparison studies with the N2 EPD</u>

It was deemed important to compare the performance of the TruDose EPD3 with the N2 EPD. Initially two - and later four N2 EPDs - were randomly selected for this intercomparison study. The N2 EPDs had previously been calibrated at LANL in a bare Cf field and a ^{137}Cs reference field. It was also an opportunity to assess the reproducibility of the TruDose EPDs as the intercomparison included neutron energy response measurements.

The EPDs (a total of up to six) were irradiated simultaneously. In the case of measurements involving the 40x40x15cm Lucite phantom (another phantom - to be described later - was also used), the EPDs were irradiated in two rows bisecting the midline of the phantom (Fig. 4). For each exposure, the EPDs were randomly positioned with no more than 3 EPDs per row.

As done previously, the albedo and fast neutron counts were recorded along with the neutron and gamma dose data. The N2 EPDs dose data were read directly from the EPD display while the count registers (when recorded) were obtained using the using an EPD2 IR reader.

Figure 4. EPDs mounted on a Lucite phantom



Energy dependence study:

These intercomparison measurements replicated the source techniques done earlier with just the TruDose EPD. All measurements were made at a distance of 100cm (unless otherwise stated) and at an angle of 0 degrees. The Lucite phantom was used exclusively.

The following Tables summarize the data collected in the following reference fields

- Bare Cf
- Poly-moderated Cf (1” wall thickness)
- Poly-moderated Cf (2” wall thickness)
- Poly-moderated Cf (3” wall thickness)
- D_2O-moderated Cf
- Bare AmBe
- Bare Cf (repeat)

Run1. Bare Cf

technique	Bare Cf	
source	FTC-Cf-7167	
d(cm)	100	
exposure time(s)	956	
Hp(10) dose rate	753	mrem/h
Hp(10) dose	200	mrem

		Reported dose (mrem)		Counts	
EPD	S/N	Neutron	Gamma	AN	FN
TruDose	100	182.4	15.6*	180	281
TruDose	108	188	8.8	197	277
N2	15795	192.4	8.4	291	101
N2	14483	218.5	8.8	280	114

*The gamma calibration factor for this EPD (HG channel) was inadvertently modified prior to the intercomparison studies which ~doubled the reported gamma dose.

Run2. 1”PE-moderated Cf

technique	1"PE_Cf	
source	FTC-CF-7167	
d(cm)	100	
Exposure time(s)	681	
Hp(10) dose rate	528.7	mrem/h
Hp(10) dose	100	mrem

		Reported dose (mrem)		Counts	
EPD	S/N	Neutron	Gamma	AN	FN
TruDose	100	116.4	10.97	177	117
TruDose	108	115.2	6.42	157	133
N2	15795	109.2	6.1		
N2	14483	122.2	6.1		
N2	797	116.3	6.1		
N2	20120	115.2	6.1		

Run3. 2”PE-moderated Cf

technique	2"PE_Cf	
source	FTC-CF-7167	
d(cm)	100	
Exposure time(s)	1055	
Hp(10) dose rate	341.2	mrem/h
Hp(10) dose	100	mrem

		Reported dose (mrem)		Counts	
EPD	S/N	Neutron	Gamma	AN	FN
TruDose	100	160.4	17.23	257	151
TruDose	108	163.2	9.5	284	128
N2	15795	120.9	9.3		
N2	14483	139.4	9.5		
N2	797	127.6	9.3		
N2	20120	125.8	9.3		

Run4. 3”PE-moderated Cf

technique	3"PE_Cf	
source	FTC-CF-7167	
d(cm)	100	
Exposure time(s)	1659.3	
Hp(10) dose rate	217	mrem/h
Hp(10) dose	100	mrem

		Reported dose (mrem)		Counts	
EPD	S/N	Neutron	Gamma	AN	FN
TruDose	100	168.4	25.37	276	146
TruDose	108	183.2	13.9	304	157
N2	15795	126.4	13.4		
N2	14483	155.5	13.9		
N2	15797	140.2	13.9		
N2	20120	120.9	13.6		

Run5. D_2O-moderated Cf

technique	D_2O-Cf	
source	FTC-CF-7167	
d(cm)	100	
Exposure time(s)	1892.3	
Hp(10) dose rate	190.2	mrem/h
Hp(10) dose	100	mrem

		Reported dose (mrem)		Counts	
EPD	S/N	Neutron	Gamma	AN	FN
TruDose	100	260.4	25.57	536	119
TruDose	108	247.6	14.8	503	120
N2	15795	186.7	14.2	813	45
N2	14483	175.7	14.8	702	44
N2	15797	184.5	14.4	814	47
N2	20120	151.2	14.3	666	40

Run6. Bare AmBe

technique	AmBe	
source		
d(cm)	50	
Exposure time(s)	2386	
Hp(10) dose rate	190.2	mrem/h
Hp(10) dose	75	mrem

		Reported dose (mrem)		Counts	
EPD	S/N	Neutron	Gamma	AN	FN
TruDose	100	90	14.9	38	210
TruDose	108	89.6	9.1	53	188
N2	15795	102.7	9.6		
N2	14483	94.9	9.7		
N2	15797	91.1	9.9		
N2	20120	102.3	9.6		

Run7. Bare Cf (repeat)

technique	Bare Cf	
source	FTC-CF-7167	
d(cm)	100	
t(s)	2386	
Hp(10)	747.2	mrem/h
dose	200	mrem

		Reported dose (mrem)		Counts	
EPD	S/N	Neutron	Gamma	AN	FN
TruDose	100	181.2	15.8	183	284
TruDose	108	171.2	8.6	174	264
N2	15795	180.7	8.2	252	97
N2	14483	169.2	8.6	210	91
N2	15797	196.1	8.6	244	112
N2	20120	183.3	8.5	252	105

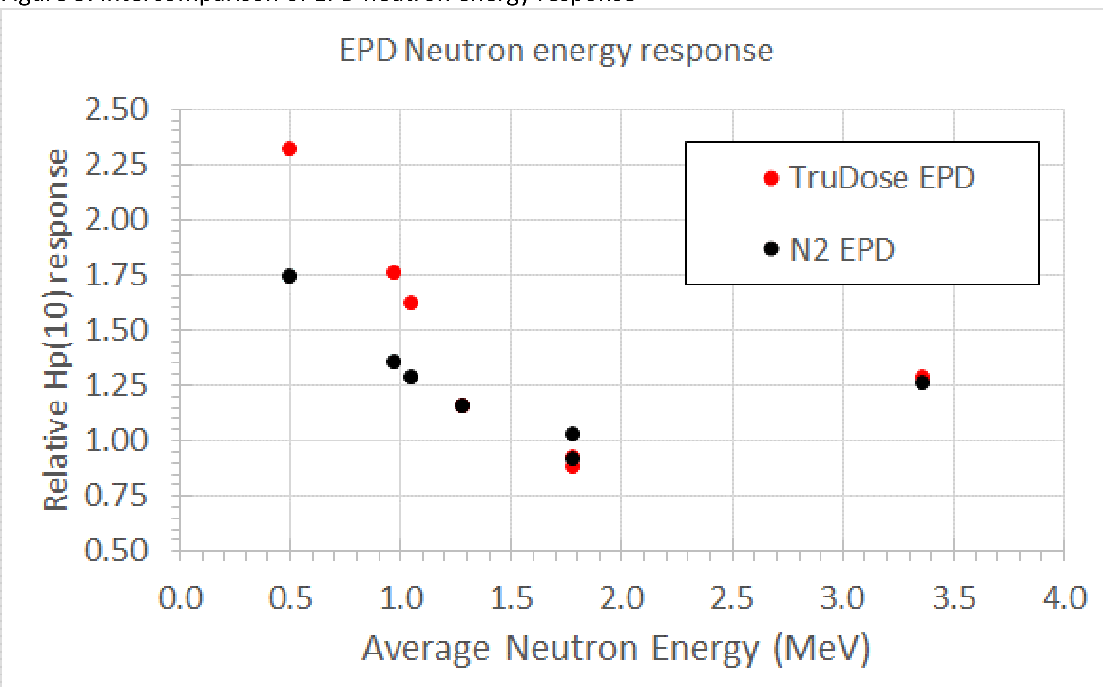
Table 4 provides an overall summary of the energy response intercomparison results for the run data above. This Table gives the averaged response of both EPD models for each neutron technique.

Table 4. Summary of intercomparison measurements on energy response

						Average Counts			
		relative to CTV			CTV	TruDose		N2	
Technique	Eavr. (MeV)	TruDose	N2	TruDose/N2	Hp(10) (mrem)	AN	FN	AN	FN
Bare Cf	1.78	0.93	1.03	0.90	200	188.5	279.0	285.5	107.5
1"PE-Cf	1.28	1.16	1.16	1.00	100	167.0	125.0		
2"PE-Cf	1.05	1.62	1.28	1.26	100	270.5	139.5		
3"PE-Cf	0.97	1.76	1.36	1.30	100	290.0	151.5		
D_2O-Cf	0.50	2.32	1.75	1.33	100	519.5	119.5	748.8	44.0
AmBe	3.36	1.28	1.26	1.02	75	45.5	199.0		
Bare Cf	1.78	0.88	0.91	0.97	200	178.5	274.0	239.5	101.3

Figure 5 plots the consolidated energy response data (Table 4) collected during the intercomparison study as a function of average neutron energy. Note that the TruDose data is in good agreement with the earlier energy response study with just the EPD3 units (Fig.1) However, it's clear that the TruDose EPD3 over responds to a greater degree than the N2 for the lower energy techniques. For example, the ratio of the EPD3 to N2 EPD response is >1.30 for the D_2O-moderated Cf technique ($E_{avr.}$ = 0.5 MeV).

Figure 5. Intercomparison of EPD neutron energy response



The intercomparison measurements also allowed the calculation of the count ratio (albedo vs fast channel) for each dosimeter model. Based on the bare and D_2O-moderated Cf data shown in Table 4, the TruDose EPD3 fast channel was found to be about 2.7 times more sensitive that the corresponding N2 channel. Conversely, the TruDose EPD3 albedo channel was about a factor of 0.72 less sensitive than the N2's albedo channel.

An analysis of the count data for the bare and D2O-moderated runs also allowed the calculation of the calibration factors (mrem/count) used by the respective fast and albedo channels of both EPD models. These surmised calibration factors are listed in Table 5. The data shown in Tables 4 and 5 clearly show marked differences in the sensitivity of the respective fast and albedo channels as well as the relative weight given to the albedo and fast counts in calculating dose. For example, in the case of the bare Cf exposures, 40% of the TruDose EPD3 total dose was found due to the albedo channel while, for the N2 EPD, this channel contributed just 20% of the total dose. As a consequence, it is not surprising that the EPD3 and N2 responded differently in neutron fields under similar conditions – especially in low average energy fields.

Table 5. Surmised calibration factors based on bare Cf and D_2O-moderated Cf measurement data

EPD model	EPD S/N	Albedo channel calibration factor (mrem/count)	Fast channel calibration factor (mrem/count)
TruDose	100	0.400	0.387
TruDose	108	0.399	0.390
N2	15795	0.148	1.48
N2	20120	0.143	1.40
N2	14483	0.152	1.55
N2	15797	0.144	1.44

Intercomparison measurements using a realistic phantom

RP-SVS has a realistic torso phantom comprised of a cadaver's skeleton covered with a tissue-equivalent material. The phantom includes air cavities to represent the lungs and tracheal tract. An x-ray image of the phantom is shown in Fig. 6a. For the purposes of this study the torso was dressed in a shirt upon which the EPDs were mounted as shown in Fig. 6b.

All exposures were done using a bare Cf source (FTC-CF-7167) at 100cm and an angle of incidence of 0^{o}. EPDs were placed inside the breast pocket (position 1) and on the opposite side of the shirt directly across from the pocket (position 2) as well as on the sternum (location 3, Fig6b).

Figure 6a. X-ray image of realistic phantom

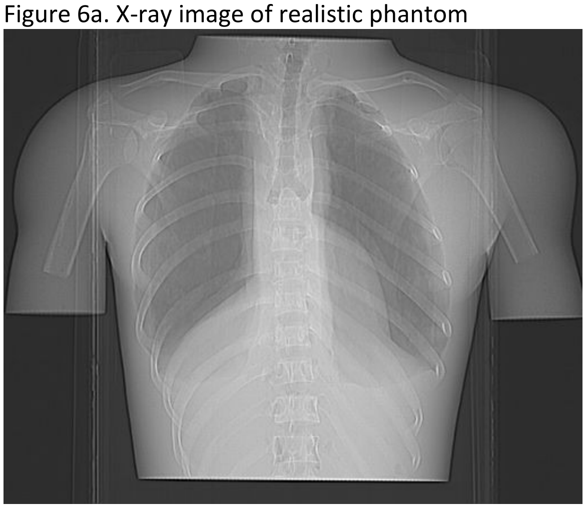


Figure 6b. TruDose EPD3 positioned on sternum

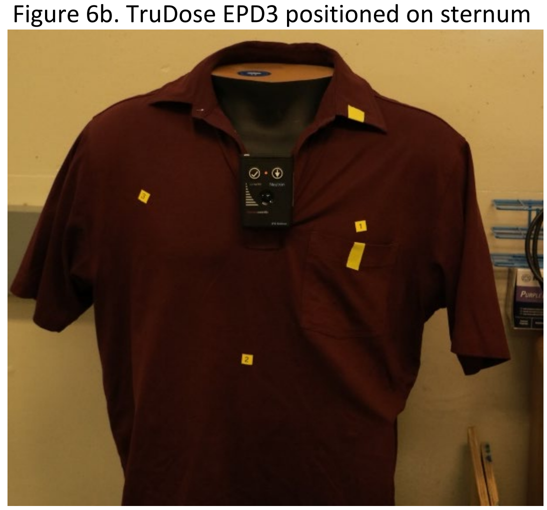


Table 6 summarizes a preliminary linearity study involving one of the TruDose EPDs (S/N 7500108) positioned on the sternum. The other EPD3 was temporarily out of service during these measurements.

Table 6 shows the EPD3 consistently under responded relative to the delivered CTV neutron dose. The average normalized response was only 75% which was primarily due to the relatively few albedo counts registered compared to the Lucite phantom. With reference to the data in Table 1, the fast counts (FN_2) recorded on the Lucite and realistic phantoms were very similar for the same delivered dose whereas the realistic phantom only provided about 57% of the albedo counts (AN_1) recorded on the Lucite phantom. These observations suggest that in practice, the TruDose EPD response (and other dosimeters based on albedo neutron detection e.g. the N2 EPD and the standard LANL TLD) will be, to a large extent, dependent on neutron attenuation and scattering within the wearer's torso. As shown above, this dependence will also be a function of neutron energy and the angle of incidence.

Table 6. Preliminary results for a TruDose EPD3 mounted on a realistic phantom

				measured dose (mrem)			counts		
time (s)	CTV Hp(10,0) dose (mrem)	EPD SN	Position	Neutron	Gamma	Total	AN_1	FN_2	Norm. response
93.3	20	108	sternum	13.20	0.80	14.00	5	29	0.660
233.1	50	108	sternum	40.00	2.00	42.00	32	69	0.800
932.6	200	108	sternum	140.00	7.89	147.89	106	247	0.700
1865.1	400	108	sternum	308.80	15.91	324.71	208	576	0.772

The realistic phantom was later used to compare the performance of both EPD models. As done previously, the bare Cf technique with the phantom positioned at 100cm from the source at an angle of 0^o was used for this intercomparison study.

The EPDs were randomly placed at one of the three measurement locations mentioned above. They were then exposed to 200 mrem after which the albedo and fast channel counts were recorded along with the measured neutron and gamma dose. Table 7 summarizes the measurement data taken during this intercomparison. The last column gives the normalized neutron response relative to the CTV dose.

Based on the limited data in Table 7, no obvious difference in normalized response regarding EPD model or location on the torso was found. The EPD3 results were in good agreement with the earlier preliminary study (Table 6) where, once again, the relatively low normalized response was due to a deficit in the number of albedo channel counts relative to a Lucite phantom. The same issue caused the N2 EPDs to under respond as well.

Table 7. Intercomparison measurement data recorded using the realistic phantom. CTV dose = 200mrem

EPD type	EPD S/N	Position	measured dose (mrem) Neutron	Gamma	Total	counts AN_1	FN_2	Norm. response
TruDose	100	2	146.0	14.96	161.0	85	299	0.730
TruDose	108	1	139.6	7.26	146.9	85	282	0.698
N2	20120	2	159.6	8.2	167.8	145	98	0.798
N2	15795	1	161.3	7.6	168.9	131	96	0.807
TruDose	100	3	142.8	14.3	157.1	79	295	0.714
N2	15797	2	150.9	8.1	159.0	172	87	0.755
TruDose	108	1	136.4	7.84	144.2	89	266	0.682
N2	14483	3	150.8	8.0	158.8	130	85	0.754

Calculated uncertainty in TruDose EPD3 and N2 EPD neutron dose measurements

An effort was made to predict the uncertainties in the EPD3 and N2 dosimeter neutron dose measurements using the sensitivity and calibration factors derived from data discussed earlier (Table 6). Towards this end, a Python program was written based on Poisson statistics to randomly sample the number of albedo and fast counts recorded by an EPD as a function of delivered dose (based on the expected number of counts in each channel). A calculated dose was derived by applying the EPD's albedo and fast neutron calibration factors (Table 5). By modelling the EPD response in this way, the uncertainty (standard deviation) in the dose could be obtained by considering many EPDs irradiated under identical conditions.

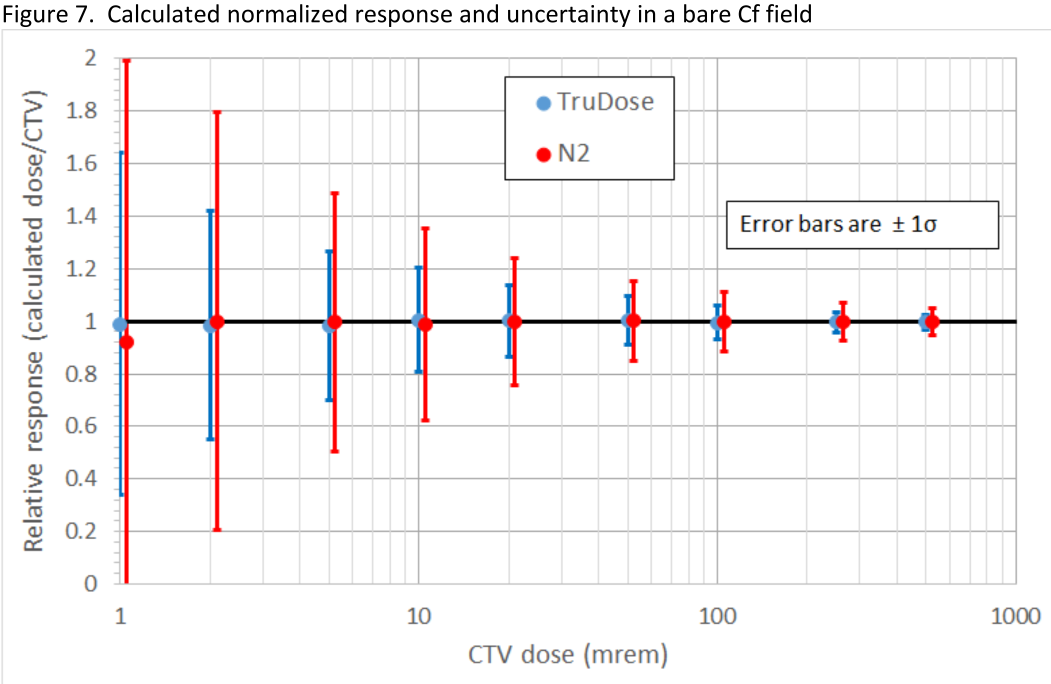
Proceeding in this fashion, Table 8 lists results based on 1000 EPDs of each model being exposed to neutron doses ranging from 1 mrem to 1 rem (bare Cf field). On average, both EPDs gave a calculated dose in excellent agreement with the CTV dose (as would be expected) but the precision of the TruDose EPD3 dose was consistently better than the N2 – due primarily to the higher sensitivity of the EPD3's fast channel (a factor of 2.7). The range of doses (minimum – maximum) calculated for the N2 EPD are seen to be greater than for the EPD3 – as anticipated based on the relatively poorer precision of the N2 EPD.

Table 8. Calculated response in bare Cf field (based on sets of 1000 EPDs)

Hp(10,0)	TruDose				N2			
CTV dose (mrem)	average dose (mrem)	std.dev (mrem)	min. (mrem)	max. (mrem)	average dose (mrem)	std.dev (mrem)	min. (mrem)	max. (mrem)
1	0.99	0.65	0	3.93	0.92	1.07	0	6.32
2	1.97	0.87	0	4.76	2.00	1.59	0	11.62
5	4.92	1.41	0.8	9.9	4.98	2.46	0.3	17.2
10	10.0	1.98	3.5	17.0	9.88	3.64	1.3	23.1
20	20.0	2.73	11.1	30.0	20.0	4.86	8.6	36.8
50	50.1	4.6	33.9	65.1	50.1	7.65	26.4	77.4
100	100	6.35	81.3	120	100	11.40	68.5	138
250	249	10.1	215	281	250	18.1	191	306
500	498	13.8	460	548	500	25.5	421	576
1000	996	20.1	939	1068	1001	34.8	901	1116

Figure 7 plots the data shown in Table 8 where the error bars denote ±1σ. Note that the N2 EPD data points have been slightly offset along the horizontal axis to aid in distinguishing the two EPD models.

Figure 7. Calculated normalized response and uncertainty in a bare Cf field



These simulated responses also indicated an uncertainty of ±20% would require neutron doses of about 40 and 120 mrem for the TruDose EPD3 and N2 EPD respectively.

Intercomparison in gamma reference fields:

The performance of the two EPD models were also compared in gamma reference fields at the CHPCF. Three sources (^{60}Co, ^{137}Cs and ^{241}Am) were used in this study as shown in Table 9. The respective fields had previously been calibrated with respect to air kerma rate with NIST-traceable ion chambers. Hp(10,0) dose rates were derived by applying the isotope-specific deep dose conversion factors ($c_{k,d,0}$) listed in ANSI 13.11 to the air kerma rates.

Table 9. Gamma sources used in the intercomparison study

source	d (cm)	Nominal activity (Ci)	$c_{k,0}$ (rad/rem)	CTV Hp(10,0) dose rate (mrem/h)	Exposure time (s)	CTV Hp(10,0) dose (mrem)
^{60}Co	100	2	1.17	906	407	102.5
^{137}Cs	100	5	1.21	1051	171 & 685	50 & 200
^{241}Am	50	3	1.89	107	1391	41.4

The EPDs were mounted on a Lucite phantom for this study – again irradiated simultaneously using two racks of three dosimeters each (in same fashion as in Fig. 4). The EPDs were randomly placed on the phantom and all exposures were done at an angle of 0 degrees.

Table 10 summarizes the results obtained in the ^{60}Co reference field. This Table includes information on the positioning of the EPDs, the reported neutron and gamma doses, the counts registered in the respective gamma registers (three for the EPD3 and two for the N2 EPD) and the normalized response relative to the delivered dose of 102.5 mrem. All four N2 EPDs

Table 10. EPD response in a ^{60}Co reference field (CTV Hp(10,0) dose = 102.5 mrem)

			measured dose (mrem)			counts			
EPD type	EPD S/N	Position	Neutron	Gamma	Total	HG	SG_1	SG_3	Norm. response
TruDose	100	Top, mid	0	87.7	87.7	122638	14734	7464	0.856
N2	15795	Bot, left	1.4	86.8	88.2	110161	22488		0.847
N2	20120	Top, left	1.9	88.6	90.5	112912	22579		0.864
TruDose	108	Bot, right	0	86.85	86.85	115604	14717	7155	0.847
N2	14483	Top, right	0.1	87.5	87.6	116254	22497		0.854
N2	15797	Bot, mid	1.4	90.2	91.6	115017	22337		0.880

registered a slight neutron dose but overall the gamma responses were in excellent agreement - albeit about 15% low in comparison to the CTV delivered dose.

The count data in Table 10 indicated that the TruDose EPD3 and N2 EPD gamma channels have very similar efficiencies. The SG (soft gamma) counts for the TruDose have been divided into two separate registers but their sum is more or less equivalent to the counts in the single SG register used by the N2. It's also clear that the gamma channels in both EPD models are many times more sensitive (counts/mrem) than their neutron counterparts.

Table 11 summarizes the data obtained for the ^{137}Cs exposures. An initial exposure of 200 mrem was done followed by a second run where 50 mrem was delivered. Again very similar performance was noted for the two EPD models. The normalized responses were essentially unity – as would be expected as they were previously calibrated in ^{137}Cs reference fields.

Table 11. EPD response in the ^{137}Cs reference field (CTV (Hp(10,0)) doses of 50 and 200 mrem)

			measured dose (mrem)			counts			
EPD type	EPD S/N	Position	Neutron	Gamma	Total	HG	SG_1	SG_3	Norm. response
N2	15795	Bot, mid	0	202.3	202.3	261337	46988		1.012
N2	15797	Bot, right	0	200.6	200.6	257749	46618		1.003
N2	20120	Top, left	0	205.2	205.2	264445	47439		1.026
TruDose	108	Top, mid	0	203.4	203.4				1.017
N2	14483	Top, right	0	203.9	203.9	274850	46489		1.020
TruDose	100	Top, mid	0	51.11	51.11	73008	7221	4147	1.022
TruDose	108	Bot, mid	0	50.92	50.92	69143	7014	4092	1.018

A final exposure was done using the CHPCF's 3Ci ^{241}Am source. Table 12 summarizes this measurement data. The normalized responses were again in good agreement though the soft gamma registers for the N2 EPD were all significantly higher that for the combined SG registers of the TruDose EPD3. The relatively low energy of the ^{241}Am gamma ray apparently accentuated a slight difference in the detection efficiencies of the respective SG registers. There's also a suggestion that the EPDs on the lower rack – especially on the right and left edges - were not uniformly illuminated at a distance of 50cm from the source as the HG and SG counts recorded by these EPDs were relatively low.

Table 12. EPD response in the ^{241}Am reference field (CTV Hp(10,0) dose = 41.4 mrem)

EPD type	EPD S/N	Position	measured dose (mrem) Neutron	Gamma	Total	counts HG	SG_1	SG_3	Norm. response
TruDose	100	Top, mid	0.4	41.7	42.1	27688	19935	13328	1.007
N2	15797	Top, left	1.4	42.1	43.5	32755	42009		1.017
N2	14483	Top, right	0	41.2	41.2	33114	41536		0.995
N2	15795	Bot, left	0	38.8	38.8	29310	40803		0.937
N2	20120	Bot, mid	0	40.3	40.3	31240	40931		0.973
TruDose	108	Bot, right	0	36.4	36.4	17691	18879	12775	0.879

Comments on the TruDose EPD3:

1) In a classic demonstration of over engineering, access to the battery compartment requires the removal of two small (M2) screws. A miniature allen key included with each EPD was extremely annoying and tiresome to use. Only later, when a 1.4mm (metric) flat head screwdriver was found to replace the allen key, was the misery of changing a battery alleviated. The N2, by comparison, has a much easier means of accessing the battery compartment.

2) The size and weight of the EPD3 and the N2 EPD are essentially equivalent.

3) There were issues with the EPD3s keeping accurate clock time – both dosimeters had to be resynced on the reader at some point. May be related to battery change outs.

4) According to the reader, unit 7500100 was calibrated in the year 2068.

5) Both EPDs reported “F071 DP” fail messages (“Dose Processing Failure”) at some point during the evaluation. A battery change and/or clearing the fault via the reader always corrected the problem. In these instances, the neutron dose was not displayed by the EPD or the reader however the Albedo and Fast counts were recorded.

6) The N2 EPD has just one button to cycle through all the displays. The EPD3 has two buttons which proved non-intuitive to use. Instead of making the EPD twice as easy to use, the additional button has made it at least twice as difficult. It didn’t help that the cues and prompts displayed by the EPD3 were not always informative as to which button to press next. As a consequence, the desktop reader was used exclusively to turn the EPD on/off and to read the accumulated dose data during this study.

7) At one point, both EPD3s appeared to have given up the ghost as the display was frozen with just a pair of symbols visible (a “!” inside a triangle and a “%”sign inside a circle).

Attempts to resuscitate eventually bore fruit but uncertain which approach was ultimately successful.

8) The EPD3 User manual mentions two fast neutron channels (FN_1 and FN_2) but only counts for the FN_2 channel were reported by the dosimeter.

9) The EPD3 has 3 gamma registers (A hard gamma (HG) and two soft gamma counters (SG_1 and SG_2)). The N2 has just two registers (HG and SG). The intercomparison study showed that the counts/mrem were essentially equivalent for the respective HG counters and the SG counters (i.e. SG_1 + SG_2 ≈ SG). As the gamma energy response of the EPD3 and N2 EPD were essentially identical, it's not clear why a third register is needed.

10) Appendix A compares the TruDose EPD and N2 EPD in several specification and performance categories of interest to users. It's not an exhaustive list but it draws heavily on product literature provided by Thermo.

<u>Comments on the Easy EPD3 desktop reader (version 1.8.0.14) and PC software:</u>

1) The EPD3 reader software was installed without any of the typical issues surrounding the installation of (any) vendor software. Kudos to Thermo.

2) The reader unfailingly and immediately recognized the presence of a TruDose EPD3 and displayed the dose and related parameters (albedo and fast counts, peak dose rate, etc...) uploaded from the EPD.

3) The reader configuration and setup options are spread over several different pages each of which has a myriad of parameter settings. Draft versions of the "EPD3 User Manual" and "Easy EPD3 manual" were supplied by Thermo. Both are over 130 pages in length.

4) Passcode-protected Administrator access is required to change most EPD settings (e.g. alarm set points).

5) The status LEDs on the reader tend to bleed their colour into the adjacent LED – so it's not always readily apparent as to current operating status.

6) Modifying the default calibration factors for both the gamma and neutron channels via the PC software (with Admin access) is straightforward though knowing how much to change each parameter (AN_1, FN_2, HG, SG_1 or SG_3) requires an off-line calculation.

Summary and conclusions:

1) The fast channel sensitivity (counts per mrem) of the EPD3 is almost 3x higher than the N2 EPD while the albedo channel is about 70% less sensitive than the N2. Overall, the uncertainty in the measured neutron dose will be less than with the N2 EPD when exposed in an identical fashion due to better counting statistics. However, the accuracy of the N2 may be better – especially in low average energy fields when calibrated with bare Cf.

2) The fast and albedo neutron calibration factors (mrem per count) for the EPD3 are essentially identical i.e. 0.4 mrem/count while the N2 has a fast channel calibration factor x10 higher than the albedo channel. As a consequence, as borne out earlier in this report, the neutron energy response of the TruDose EPD3 and the N2 EPD cannot be expected to be equivalent. Indeed, in low average energy neutron fields (≈0.5 MeV), differences of more than 30% were observed during this evaluation.

3) The EPD3 and the N2 EPD demonstrate a similar angular response in a bare Cf field. Both EPDs increasingly under report Hp(10,θ) dose as the angle of rotation is increased. This finding has previously been observed by other researchers for the N2.

4) The gamma response of both EPD models are essentially equivalent – based on their performance in ^{241}Am, ^{137}Cs and ^{60}Co reference fields.

5) Both EPD models under reported neutron dose when mounted on a realistic phantom – mainly due to the lack of albedo neutrons. In practice, EPD response will be a function not only of the energy and directional dependence of the neutron field but also the attenuation/scattering properties of the wearer's body, the movement of the worker within the neutron field and where the EPD is positioned on the body.

6) Overall, this evaluation study found the TruDose EPD3 from a performance perspective to be a valid contender to replace the N2 EPD. There are issues that Thermo might address to improve the use and performance of the TruDose EPD3:

    a. Modifying the battery compartment so it can be opened without a special tool.
    b. Improve the cues on the EPD display to make clearer the functionality of each button.
    c. Look into the "F071 DP" fault condition - in our experience, it's not an issue with the N2 EPD. Other fault conditions as noted above were also observed.
    d. Upgrade the EasyEPD3 reader to be compatible with the N2 EPD.

Appendix A. Comparison table for the TruDose and N2 EPDs

Feature or property	N2	TruDose
dimensions (cm)	8.6 x 6.2 x 1.85	8.6 x 6.3 x 2.1
weight (g)	108	106
battery	1 x AA	1 x AA
ease of battery change out	easy	Unnecessarily complicated
gamma energy range (MeV)	0.025 - 7 MeV	0.016 - 1.5 MeV
neutron energy range (MeV)	thermal - 15 MeV	thermal - 20 MeV
gamma dose rate range		0.1 mrem/h - 200 rem/h
neutron dose range		100 mrem/h - 1000 rem/h
# of buttons to navigate EPD	1	2
ease of use	intuitive	not intuitive
communications (readers are not compatible)	IR reader or desktop reader	IR reader or desktop reader
LCD display	configurable	configurable
telemetry	external module	internal, if equipped
alarm annunciation modes	LED, audible	LED audible, vibration
over range alarm	yes (10 rem)	yes (1000 rem)
over range dose rate		yes (up to 5000 rem/h)
dose warning alarm (photons & neutrons)	yes & fully configurable	yes & fully configurable
dose limit alarm (photons and neutrons)	yes & fully configurable	yes & fully configurable
dose rate warning alarm (photons and neutrons)	yes & fully configurable	yes & fully configurable
dose rate limit alarm (photons & neutrons)	yes & fully configurable	yes & fully configurable
combined neutron/gamma dose alarm	yes & fully configurable	yes & fully configurable

Feature or property	N2	TruDose
gamma energy response at 0^{o} (wrt 137Cs)	<±20% up to 1.5MeV, up to ±50% for 1.5-10 MeV	<±10% up to 1.5MeV, -15% to 50% for 1.5-10 MeV
gamma angular response (137Cs)	±20% from 0^{o}-75^{o}	
neutron accuracy for AmBe source	±20%	
neutron angular response (AmBe)	±50% from 0^{o}-75^{o}	
battery alarm	yes	yes
abuse alarm	yes	yes
count down alarm	yes	yes, (stay time)
EPD failure alarm	yes	yes
dose peak mode	yes	yes
clear dose from EPD	yes (but not combined dose)	yes (but not total dose)
dose profile	500 records max.	1792 records max.
batch write capability	yes	yes
backlight	yes	yes
gamma registers	2 (HG and SG)	3 (HG, SG_1 , SG_3)
neutron registers	2 (AN and FN)	2 (AN_1 and FN_1)
diagnostics	yes	yes
abuse log	yes	yes
User assignment at issue	User ID & name	Up to 3 user ID fields, task name and task ID